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**Title: SYSTEM AND METHOD FOR
READING POWER METERS**
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Title: SYSTEM AND METHOD FOR READING POWER METERS

Field of the invention

[0001] The invention relates to a system and method for reading power meters. More particularly, the invention relates to a system and method for more efficiently reading power meters and providing an indication of power usage to a user of the power meter.

Background of the invention

[0002] Power meters are used by utility companies for measuring and providing a readout for the quantity of electricity that has been used in a commercial or residential establishment. Conventionally, if a person, such as a homeowner, wanted to monitor energy consumption, then the person would physically go outside to the location of the power meter to read the power meter. This process is labor intensive, can be subject to human error and in certain circumstances may not be safe for the person. Accordingly, there is a movement towards automatic power meter readers that integrate the capability of measuring the amount of electricity and communicating the measurement to the utility company using either wired or wireless signal transmission. However, automatic power meter readers are generally limited to newer power meter installations. Consequently, there is a need for a power meter reader that can be retrofitted to the various types of existing power meters.

[0003] Automatic power meter readers are typically retrofitted to existing power meters and are typically connected to the power lines power to obtain power. However, it would be more convenient to use one or more batteries for a power source; i.e. the automatic power meter reader would be easier to install since no connections to a power source would have to be made. Unfortunately, the operations that are carried out by the automatic power meter readers, such as detecting the rotation of the power meter disk and transmitting information related to power consumption of the structure are power hungry operations that would result in the frequent replacement of the batteries. This is inefficient and cumbersome. Accordingly, it would be

advantageous to have a power meter reader that operates in an efficient manner for prolonging battery lifetime.

[0004] Another common issue for power utility companies is dealing with unsatisfied consumers who complain about their high electric bills. What is needed is technology that allows a consumer to know how much electricity they are consuming, in dollars and cents or kilowatt-hours, and how much their electric bill will be at the end of the month. The consumers can use the feedback on the amount of electricity that they are using to reduce high electric bills. There is also a growing pressure to increase energy efficiency, conserve energy resources and reduce atmospheric pollution. This can be achieved with increased consumer awareness of the amount of energy that they are consuming. In fact, studies show that energy savings of up to 15% or more is possible when consumers get enough information to make meaningful decisions about energy consumption.

Summary of the invention

[0005] The invention provides a detection unit that is mounted to the power meter unit and a display unit that is remotely located with respect to the detection unit; one possibility is to mount the display unit within the structure for which the power meter unit is monitoring energy consumption. The detection unit monitors the indication of power consumption on the power meter (which is usually the rotation of the power meter disk of the power meter) and provides information related to the power consumption to the display unit. The display unit then displays the power consumption information to a consumer who is responsible for the power consumption of the structure. The display unit can provide a variety of information such as power consumption in a kW/hr or in a dollar amount (or another foreign currency) as well as the greenhouse gas that is being emitted due to the power usage.

[0006] Advantageously, the detection unit provides one or more energy efficient features for reducing its own energy consumption. For instance, the detection unit can enter a sleep mode during certain time intervals while detecting the power consumption indicated by the power meter unit.

Alternatively, or in addition, the detection unit can generate a prediction model that represents information related to the power consumption and transmit the prediction model parameters, rather than raw data, to the display unit which uses the prediction model parameters to show power consumption (this may be done in real-time). This reduces the amount of data that is transmitted to the display unit. This also reduces the amount of transmissions that are sent to the display unit since data need only be transmitted when the values of the prediction model parameters change.

[0007] The invention also provides an attachment means for attaching the detection unit to the power meter unit. The attachment means is adapted for allowing the detection unit to be attached to a wide variety of power meter units. In particular, the attachment means includes a clamping means that is fitted around the perimeter of the body of the power meter unit. The attachment means also includes an arm that houses a sensor unit for sensing the indication of power consumption of the power meter unit. The arm includes an extension means for extending the length of the arm so that the location of the sensor unit can be properly adjusted over an appropriate location on the power meter unit. The arm may also include a pivot means for angling the arm with respect to the main body of the detection unit.

[0008] In one aspect, the invention provides a power meter reader system for automatically reading a power meter unit mounted on a structure that is consuming power. The power meter unit includes an indication with a cyclical property having a period that varies at a rate indicative of power consumption of the structure. The system comprises a detection unit mounted on the power meter unit for monitoring the power consumption. The detection unit comprises a sensor unit disposed adjacent to the power meter unit for monitoring the cyclical property of the indication and generating a consumption detection signal; a processing unit connected to the sensor unit for receiving the consumption detection signal and generating an information signal, the processing unit further generating a sensor enable signal to enable the sensor unit for only a portion of the cyclical property of the indication, the

portion coinciding with a time interval indicating the completion of one period of the cyclical property, the time interval being shorter than the period of the cyclical property; and, a transmitter connected to the processing unit for receiving the information signal and transmitting a transmission signal. The power meter reader system further includes a display unit located remotely with respect to the detection unit. The display unit receives the transmission signal and displays the power consumption.

[0009] In another aspect, the invention provides a power meter reader system for automatically reading a power meter unit mounted on a structure that is consuming power. The power meter includes an indication with a cyclical property having a period that varies at a rate indicative of power consumption of the structure. The system comprises a detection unit mounted on the power meter unit for monitoring the power consumption. The detection unit comprises a sensor unit disposed adjacent to the power meter unit for monitoring the cyclical property of the indication and generating a consumption detection signal; a processing unit connected to the sensor unit for receiving the consumption detection signal and generating an information signal, the processing unit including a prediction unit for generating values for prediction model parameters for predicting energy consumption data derived from the consumption detection signal and incorporating the values of the prediction model parameters into the information signal; and, a transmitter connected to the processing unit for receiving the information signal and transmitting a transmission signal. The power meter reader system further includes a display unit located remotely with respect to the detection unit. The display unit receives the transmission signal and displays the power consumption of the structure based on the prediction model parameters.

[0010] In yet another aspect, the invention provides a housing for a detection unit for automatically reading a power meter unit mounted on a structure that is consuming power. The power meter unit includes an indication with a cyclical property having a period that varies at a rate indicative of power consumption of the structure. The housing comprises a

main body for housing internal electronics; an extension member connected to the main body, the extension member having a head region for housing a sensor unit; and, an attachment means connected to the main body for mounting the main body on the power meter unit.

[0011] In a further aspect, the invention provides a detection unit for use with a power meter unit mounted on a structure that is consuming power, the power meter unit including an indication with a cyclical property that varies at a rate indicative of power consumption of the structure. The detection unit is mounted on the power meter unit for monitoring the power consumption and comprises a sensor unit disposed adjacent to the power meter unit for monitoring the cyclical property of the indication and generating a consumption detection signal; and, a processing unit connected to the sensor unit for receiving the consumption detection signal and generating an information signal, the processing unit further generating a sensor enable signal to enable the sensor unit for only a portion of the cyclical property of the indication, the portion coinciding with a time interval indicating the completion of one period of the cyclical property, the time interval being shorter than the period of the cyclical property.

[0012] In yet another aspect, the invention provides a detection unit for use with a power meter unit mounted on a structure that is consuming power, the power meter unit including an indication with a cyclical property having a period that varies at a rate indicative of power consumption of the structure. The detection unit is mounted on the power meter unit for monitoring the power consumption and comprises a sensor unit disposed adjacent to the power meter unit for monitoring the cyclical property of the indication and generating a consumption detection signal; and, a processing unit connected to the sensor unit for receiving the consumption detection signal and generating an information signal, the processing unit including a prediction unit for generating values for prediction model parameters for predicting power consumption data derived from the consumption detection signal and

incorporating the values of the prediction model parameters into the information signal.

[0013] In another aspect, the invention provides a method for automatically reading a power meter unit mounted on a structure that is consuming power, the power meter unit including an indication with a cyclical property that varies at a rate indicative of power consumption. The method comprises:

- a) sensing values for the cyclical property of the indication using a sensor unit and generating a consumption detection signal;

- b) generating an information signal based on data from the consumption detection signal; and,

- c) generating a sensor enable signal to enable the sensor unit for only a portion of the cyclical property of the indication, the portion coinciding with a time interval indicating the completion of one period of the cyclical property, the time interval being shorter than the period of the cyclical property.

[0014] In a still further aspect, the invention provides a method for automatically reading a power meter unit mounted on a structure that is consuming power, the power meter unit including an indication with a cyclical property having a period that varies at a rate indicative of power consumption of the structure. The method comprises:

- a) sensing values for the cyclical property of the indication using a sensor unit and generating a consumption detection signal; and,

- b) generating an information signal based on data from the consumption detection signal by generating values for prediction model parameters to predict power consumption data derived from the consumption detection signal and including the values of the prediction model parameters in the information signal.

Brief description of the drawings

[0015] For a better understanding of the invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings which show an exemplary embodiment of the invention and in which:

Figure 1 is a block diagram of an exemplary embodiment of a power meter reader system in accordance with the invention;

Figure 2 is a block diagram of another exemplary embodiment of a power meter reader system in accordance with the invention;

Figure 3a is a schematic of an exemplary embodiment of a sensor unit that can be used in the power meter reader systems of Figures 1 and 2;

Figures 3b-3f are a series of illustrations of the operation of the sensor unit of Figure 3a with respect to the motion of the black mark on the power meter disk;

Figure 4 is shows a data structure that may be used for transmitting data in the power meter reader systems of Figures 1 and 2;

Figure 5 is a front view of an exemplary physical embodiment of a display unit that can be used with the power meter reader systems of Figures 1 and 2;

Figure 6a is a front view of an exemplary physical embodiment of a detection unit attached to a power meter that can be used with the power meter reader systems of Figures 1 and 2;

Figure 6b is a perspective view of the detection unit of Figure 6a; and,

Figure 6c is an exploded isometric view of the housing of a portion of the detection unit of Figure 6a.

Detailed description of the invention

[0016] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the invention.

[0017] Further, it will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

[0018] Referring first to Figure 1, shown therein is a block diagram of an exemplary embodiment of a power meter reader system **10**. The power meter reader system **10** comprises a detection unit **12** and a display unit **14**. The detection unit **10** is mounted to a power meter unit **16** and the display unit **14** is mounted in a convenient location within the structure for which the power meter unit **16** is monitoring power consumption. The detection unit **12** and the display unit **14** are preferably wirelessly coupled. However, the detection unit **12** and the display unit **14** may be hardwired to each other in known manner. The physical structure of the detection unit **12** and the manner in which the detection unit **12** is mounted to the power meter unit **16** are discussed in further detail below.

[0019] As is commonly known to those skilled in the art, the power meter unit **16** is typically mounted on the outside wall of the structure for which the power meter unit **16** is monitoring electrical power usage (the meter unit **16** may also be on the inside of the structure). The power meter unit **16** has a clear plastic or glass cover for allowing the power usage to be read while protecting the power meter unit **16** from the elements such as rain or snow and against possible tampering. The power meter unit **16** also has a

power meter disk **18**, shown schematically for illustrative purposes, which rotates at a speed that indicates power usage. The power meter disk **18** is oriented approximately perpendicular to the cover of the power meter unit **16** and has a black mark **20** that is in the shape of a small circular arc along the top and edge of the power meter disk **18**. The power meter unit **16** also has a plurality of dials (not shown) that indicate the current electrical power usage of the structure. The dials rotate in accordance with the rate of rotation of the power meter disk **18**.

[0020] It should be understood by those skilled in the art that the power meter unit **16** may be a digital power meter unit with an alternative indication of power consumption such as a digital representation of the power meter disk **18**, or a vertical or horizontal bar on an LED with a mark that moves across the bar at the rate that the black mark on the power meter disk revolves. Other representations are also possible. The black mark **20** on the power meter disk **18** will hereafter be used in the description of the operation of the power meter system for ease of description. However, it should be understood that the black mark can generally be considered to be an indication having a cyclical property that has a period with a varying rate and that there are other types of power meters with other forms of indication as described above.

[0021] The detection unit **12** comprises a sensor unit **22**, a processing unit **24**, a temperature unit **26**, a transmitter **28** and a power source **30**. The sensor unit **22** detects the rotation of the power meter disk **18** and provides a consumption detection signal **32** to the processing unit **24** to indicate the rotation frequency of the power meter disk **18**. The sensor unit is described in further detail below. The temperature unit **26** measures the outdoor temperature and provides a temperature signal **34** to the processing unit **24**.

[0022] The temperature unit **26** is optional. However, it is preferable to include the temperature unit **26** for obtaining temperature information that can be used by the power meter reader system for augmenting the power consumption as is described in further detail below. The temperature unit **26** includes a temperature sensor, such as a thermister, and a resistor used to

bias the temperature sensor (both not shown). The value of the resistor is preferably chosen to draw the least amount of current possible while still allowing the temperature sensor to provide a reading of the outside temperature. The temperature reading is a raw analog voltage level that is dependent on the outside temperature. The raw analog voltage level is sent by the transmitter **28** to the display unit **14** without any preprocessing. The display unit **14** then converts the raw analog voltage level to a temperature value. The display unit **14** performs the conversion to reduce the amount of processing that is done by the processing unit **24** and hence reducing the energy consumption of the detection unit **12**.

[0023] The detection unit **12** includes one or more components for reducing power consumption as is described in further detail below. For instance, low voltage components are used to reduce power consumption. Further, the operating parameters of the detection unit are chosen to reduce power consumption. For instance, a low clock frequency, such as 32 kHz for example, is used for the processing unit **24**. In addition, the operating voltage of the sensor unit **22**, the processing unit **24**, the temperature unit **26**, and the transmitter **28** is reduced. Further certain components of the detection unit **12**, such as the sensor unit **22**, certain modules of the processing unit **24**, and the RF circuitry of the transmitter **28** are placed into sleep mode when not in use. The sleep mode used for the sensor unit **22** is described in further detail below.

[0024] The processing unit **24** uses the consumption detection signal **32** and the temperature signal **34** as well as other information, as is described further below, for creating an information signal **36**. The information signal **36** is sent to the transmitter **28** which generates and wirelessly transmits a transmission signal **38** to the display unit **14**. The transmitter **28** modulates the information signal **36** for transmission at a suitable transmission frequency. The transmitter **28** is any suitable transmitter that has low current consumption and the ability to operate in a sleep mode. The transmitter **28** also preferably provides error correcting codes for encoding the information

signal. Error correcting codes allows a certain amount of errors to be introduced during transmission, yet these errors can be corrected at the display unit **14**. The benefit of such a transmission scheme is that the range for wireless transmission is increased for the same amount of power consumption. Alternatively, the power consumption can be reduced while still ensuring that the range for wireless transmission is sufficient. The transmitter **28** also provides data for a CRC check that can be used by the display unit **14** to throw out corrupt messages. This is beneficial since, as the power of the wireless transmission gets lower (i.e. the signal to noise ratio (SNR) gets lower), it is more likely that the wireless transmission can become corrupted. Since, reduced power consumption is a goal of the power meter reader system **10**, transmission is preferably done at a low SNR. Consequently error correction codes and data for a CRC check is used to ensure that data is correctly received by the display unit **14**.

[0025] The power source **30** provides power for the operation of the detection unit **12**. The power source **30** is connected to the processing unit **24** which distributes the power to the remaining components of the detection unit **12**. Preferably the power source **30** is a battery such as a 3.6V lithium AA battery for example.

[0026] The sensor unit **22** is physically positioned adjacent to the power meter disk **18** for detecting the rotation of the power meter disk **18**. The sensor unit **22** comprises an IR emitting diode and at least one photo diode (described in more detail below). The IR emitting diode transmits a modulated light beam to the surface of the power meter disk **18**. The modulated light beam is reflected by the power meter disk **18** at a certain level. However, when the modulated light beam encounters the black mark **20**, the light beam is reflected at a lower level. Accordingly, the sensor unit **22** detects revolutions of the black mark **20** based on a lower amount of reflected light (this may also include the total absence of reflected light). The sensor unit **22** generates a pulse in the consumption detection signal **28** for each detection of the revolution of the black mark **20**. The modulated light beam is modulated at

a frequency of approximately 38 kHz so that sunlight can be filtered out by the sensor unit **22** (other suitable modulation frequencies may also be used). The use of modulation also reduces the power that is required by the sensor unit **22** since the modulation requires that the IR emitting diode is turned off for very brief periods of time. To further reduce energy consumption, the sensor unit **22** receives an enable control signal from the processing unit **24**. Accordingly, the sensor unit **22** is only operational for a portion of the rotation of the power meter disk **18** which coincides with the passage of the black mark **20** past the sensor unit **22** (i.e. the sensor unit **22** is turned off until the black mark **20** is expected to return). This is described in more detail below.

[0027] The processing unit **24** controls the operation of the detection unit **12** such that the detection unit **12** operates in an energy efficient manner. In the exemplary embodiment of Figure 1, the processing unit **24** includes a control unit **42**, a tracking unit **44**, a prediction unit **46**, a compression unit **48** and a memory unit **50** (some of these components may be omitted in other embodiments as discussed further below). The control unit **42** directs the operation of the detection unit **12** to enable the activation of the sensor unit **22**, to generate power meter disk rotation information, read outdoor temperature, generate packets of information to send to the display unit **14** and detect if the power source **30** is low. The processing unit **24** is implemented by any suitable, ultra-low power microcontroller with associated hardware and software.

[0028] The tracking unit **44** tracks the movement of the power meter disk **18** based on the current speed and the maximum acceleration of the power meter disk **18**. The tracking unit **44** uses this information to dynamically set a sleep period for the sensor unit **22**. The sleep period is provided to the control unit **42** each time the sleep period is updated. During the sleep period, the control unit **42** disables the operation of the sensor unit **22** via the enable control line **40** and enables the sensor unit **22** otherwise. The sleep period can be based on an estimate of the return time of the black mark **20** for the next revolution of the power meter disk **18**. The return time of the power meter

disk **18** can be estimated based on the last two detections of the black mark **20**. Alternatively, the last detected revolution of the power meter disk **18** can be used to estimate the revolution rate of the power meter disk **18**. For example, if the tracking unit **44** estimates that the last return time of the meter disk **18** took 2 seconds, then it is highly likely that the next cycle will be somewhere close to that same time period.

[0029] The kinematics of the power meter disk **18** can also be used to determine the minimum time required for the power meter disk **18** to make the next full revolution. The sleep period can then be chosen accordingly. Based on kinematics, the fastest revolution time for the power meter disk is given by equation 1:

$$t_f = t_c / (1 + \text{MAX_DELTA} * t_c / 25920000) \quad (1)$$

where t_f is the fastest revolution time for the power meter disk **18**, t_c is the last time it took for one full revolution, MAX_DELTA is the value of watts "kicking" in during the next cycle (i.e. revolution of the power meter disk **18**) and the value 25920000 is a constant. The constant is calculated by multiplying the kWh factor of the power meter **16** (which is typically 7.2 Whr) with the amount of seconds in 1 hour and the constant 1000. The value of t_c can be based on the average or instantaneous revolution speed of the power meter disk **18**. There can be an array of values that can be used for MAX_DELTA. Some exemplary numbers for MAX_DELTA include 2000, 5000 or 10000. The particular value of MAX_DELTA that is used depends on the current revolution speed of the power meter disk **18**. If the disk **18** is revolving at a slow speed, then a larger value of MAX_DELTA, such as 5000, can be selected because there are many devices that can be turned on to increase power consumption within the structure. However, if the disk **18** is revolving at a high speed, then a lower value of MAX_DELTA, such as 2000, can be selected. This allows for the selection of a longer sleep period without missing the next revolution of the black mark **20**. This is effective at high power consumption levels associated with the structure (i.e. at fast revolution speeds for the power meter disk **18**) since there aren't many more devices that can be

turned on, or turned on at a higher level, in the structure to consume more energy and make the disk **18** revolve at a faster rate. However, at lower revolution rates, the sleep period cannot be set as long using this method.

[0030] In an alternative, the tracking unit **44** can set the sleep period according to a percentage of the last full revolution time of the power meter disk **18**. For example, if the power meter disk **18** took 3 seconds for the last revolution and a 50% sleep period is set by the tracking unit **44**, then the sensor unit **22** will sleep for 1.5 seconds after the last detection the black mark **20** and then "wake-up" to detect the next occurrence of the black mark **20**. This form of tracking is somewhat adaptive in nature. For example, if the rotation of the power meter disk **18** slows down to 5 seconds per revolution, the control unit **22** will change the sleep period to 2.5 seconds. However, if the rotation of the power meter disk **18** speeds up, there is a potential for cycles to be missed. However, once the sensor unit **22** is turned back on it will adjust to the speed of the meter disk **18**.

[0031] The percentage used to determine the sleep period can also be changed depending on the speed of the power meter disk **18**. For instance, if the power meter disk **18** is rotating at a high speed, then the sleep period percentage can be set to a higher value such as 90%, for example. Alternatively, if the power meter disk **18** is rotating at a slower speed, then the sleep period percentage can be set to a lower value such as 50%, for example. Accordingly, when the power meter disk **18** transitions from a low revolution speed to a high revolution speed, a progressively higher sleep period percentage can be used. The rationale behind this is that at high rotation rates, the power meter disk **18** is unlikely to travel any faster since most of the devices in the structure that consume energy are already turned on which causes the power meter disk **18** to rotate at such a high rate. In this case, it is extremely unlikely that the power meter disk **18** will rotate any faster. Accordingly, setting a high sleep period in this case will most likely not result in any missed detections of the black mark **20**. Alternatively, when the power meter disk **18** is rotating at a slow rate, it is quite likely that the power

meter disk **18** can speed up quite quickly. Firstly, the inertia of the power meter disk **18** is low so that the power meter disk **18** can change speeds quickly. Secondly, and more importantly, since the power meter disk **18** is rotating at a slow speed, there are many devices that can be turned on, or alternatively turned on at a higher setting, which increases power consumption and therefore the speed of the power meter disk **18**. This is even more pronounced depending on the time of day, when it is more likely that devices are turned on and off. Therefore, at low speeds, to avoid missing detections of the black mark **20**, the sleep period is typically set to a lower percentage of the cycle time of the power meter disk **18**.

[0032] Furthermore, in either a periodic or aperiodic fashion, the sensor unit **22** does not enter sleep mode during a complete rotation of the power meter disk **18**, so that the sensor unit **22** can avoid becoming out of sync with the rotation of the power meter disk **18**. For example, if a rotation of the power meter disk **18** is missed, the sensor unit **22** will not be aware of this and will assume that the revolution time of the power meter disk **18** is longer than it actually is and will add the extra time to the current revolution cycle. This may cause the sensor unit **22** to miss successive cycles. To avoid this, full cycle detection can be used at various times during the operation of the detection unit **12**.

[0033] In another alternative, the tracking unit **44** can adjust the sleep period based on the time of day since the amount of power consumption, and hence the rotation speed of the power meter disk **18**, can vary depending on the time of day. For instance, power consumption may decrease at night, and it also very unlikely that additional devices will turn on at night, so the sleep period can be set to a larger percentage of the rotation speed of the power meter disk **18** at night. In another alternative, the sleep period can be based on the last X (e.g. 100) revolution times for the power meter disk **18**.

[0034] In another alternative, the tracking unit **44** can adjust the sleep period based on the amount of energy remaining in the power source **30**. For instance, if the power source **30** is a battery and the control unit **42** detects a

low amount of power remaining in the battery, then the sleep period can be extended to conserve power consumption by the detection unit **12** at the cost of reduced accuracy of counting the number of rotations of the power meter disk **18**.

[0035] In each of the above cases, the tracking unit **44** also sets upper and lower limits for the sleep period. An upper sleep period limit is set so that the sensor unit **22** will not miss the detection of too many cycles should the rotation of the power meter disk **18** go from a very slow speed to a very high speed before the sensor unit **22** wakes up. The upper sleep period limit is set to be approximately half the minimum time the black mark **20** is in view of the sensor unit **22**. This is based on the Nyquist rate for sampling the black mark **20** on the power meter disk **18** and ensures that the sensor unit **22** will be on often enough to detect the black mark **20** even for the fastest speed at which the power meter disk **18** can rotate. This limit is capped at approximately 90-95% of the revolution time for the power meter disk **18**. Conversely, the lower sleep period percentage, which is used at low revolution speeds of the power meter disk **18**, is set based on the fact that it is known that the power meter disk **18** can go much faster as there are more loads that are available to consume power and hence increase the rotational speed of the power meter disk **18**. This limit is capped at approximately 50%.

[0036] The prediction unit **44** is used to alter the rate at which the transmitter sends the transmission signal **38** to the display unit **14**. Accordingly, the data sent to the display unit **14** is not necessarily sent at a periodic rate. Rather, the prediction unit **44** uses prediction techniques to generate parameters for a prediction model that predicts the revolution of the power meter disk **18**. The values of the model parameters are sent to the display unit **14** and the display unit **14** uses the values of the prediction model parameters to "simulate" the rotation of the power meter disk **18** and calculate future values of power usage in real-time. In particular, depending on the accuracy of the prediction model, the values of power usage are updated by the display unit **14** at the same rate that the power meter disk **18** is actually

rotating. The usage of prediction model parameters advantageously allows the display unit **14** to show the current power consumption without the detection unit **12** using up the power source **30** by sending frequent transmissions to the display unit **14**. Accordingly, the detection unit **12** reduces energy consumption since transmission occurs less often. However, it appears as if the display unit **14** is receiving a steady stream of data, since the display unit **14** is providing power consumption data of the structure in real-time, even though the data transmissions from the detection unit **12** are not periodic. Also, it should be understood that when each data transmission is received, the display unit becomes synchronized with the real number of cycles that have occurred since this information is provided by the detection unit **12**. Another advantage of using a prediction model, is that the values of the prediction model parameters are transmitted rather than the actual data; this reduces the amount of data that is transmitted to the display unit **14** which also reduces the power consumption of the detection unit **12**.

[0037] The values for the model parameters that are sent to the display unit **14** are updated when the model becomes out of sync with the readings taken by the sensor unit **22**. For instance, when the prediction unit **46** determines that the prediction model has a prediction error ϵ_{pred} that is greater than a predetermined prediction error threshold, such as 1 kWh for example, the prediction unit **46** recalculates values for the prediction model parameters, based on the latest values of the consumption detection signal **32**. The updated values of the prediction model parameters are then sent to the display unit **14**. The prediction unit **46** can also set a minimum and maximum time period between transmissions so that the detection unit **12** does not send too many transmissions to the display unit **14** while at the same time communicating at a basic rate to let the display unit **14** know that the detection unit **12** is still operational. Exemplary minimum and maximum time limits for sending transmissions are 3 minutes and 20 minutes respectively. The effect of the minimal time period for transmissions can also be

implemented by setting the prediction error low enough so that the prediction error may be violated in a short period of time.

[0038] The complexity and accuracy of the prediction model is based on the computing power of the processing unit **24**, the type of prediction algorithm being used, the amount of data from the consumption detection signal **32** that is used for prediction, and the determinism of the data in the consumption detection signal **32**. The complexity and accuracy of the prediction model is also governed by the amount of power that must be expended by the detection unit **12** while employing the prediction model; it is desirable for the power consumption of the detection unit **12** to be as low as possible. An example of a prediction model that can be used by the prediction unit **46** is given by equation 2:

$$\tilde{s}[n] = s[n - n_{lag}] + n_{lag} \cdot v \quad (2)$$

where \tilde{s} is the predicted power consumption in the structure, s is the actual power consumption in the structure, v is the velocity of the power meter disk **18** (based on the last k values of s), n is the current data index and n_{lag} is the number of index points into the prediction. The velocity (i.e. rotational speed) is inversely proportional to the last revolution time of the power meter disk **18** and therefore proportional to the power consumption of the structure. In this sense, the velocity is the average velocity of the power meter disk **18**. The velocity could also be based on the instantaneous velocity of the power meter disk **18** according to the equation 1 which is based on kinematics. The index n is in terms of discrete time. For example, for each interval of n , 3 seconds may have expired. For instance, $n = 1$ means 3 seconds have passed.. The value $s[n - n_{lag}]$ represents the last known power consumption value before the current version of prediction began. Accordingly, the prediction parameters that are transmitted for this prediction model are the absolute cycle count and the time for the last revolution.

[0039] The prediction model also employs a prediction error that is used to recalculate values for the parameters of the prediction model when

the prediction error of the prediction model exceeds a certain level, such as, for example, $\varepsilon_{\text{pred}} = 200$ cycles or equivalently 10 cents based on a kh factor of 7.2 Whr and an energy rate of 7 cents per kWh. Other suitable examples of prediction model errors include $\varepsilon_{\text{pred}} = 20$ cycles (i.e. 1 cent) or 100 cycles (i.e. 5 cents).

[0040] The prediction model shown in equation 2 is referred to as a LAST prediction model since it is based on the velocity of the power meter disk **18** in the latest revolution. Another example for a prediction model that can be used is referred to as a LINEAR prediction model. Although the LAST prediction model is linear in that it uses the latest speed of the power meter disk **18** as the velocity, the LINEAR prediction model uses the difference in cycle count between successive transmissions of data and the elapsed time between the transmissions from the transmitter to calculate the velocity. The remainder of the LINEAR prediction model operates in the same fashion as the LAST prediction model.

[0041] Other classes of prediction models may also be used such as AR, MA, or ARMA models. Kalman filtering or other forms of tracking may also be used. Simple, nonlinear prediction models may also be used. However, it is preferable to use a prediction model that has low computational complexity for reducing the power consumption of the detection unit **12**. This means that the order of the prediction model is high enough to give accurate results but low enough to avoid undue amounts of computational complexity.

[0042] The control unit **42** generates information for transmission. In one embodiment, the generated information includes:

- a) the time in milliseconds that it took for the last revolution of the power meter disk **18**;
- b) the cycle count (i.e. the number of revolutions of the power meter disk **18** that have been counted by the detection unit **12**);
- c) the voltage status of the power source **30**;
- d) the outside temperature;

e) a device address (the transmitter **28** has a unique address);
and,

f) cyclic redundancy check (CRC) data.

The model parameters that are sent from the detection unit **12** to the display unit **14** depend on the particular prediction model that is being used. One option is to base the prediction models on the cycle count, and the latest revolution time of the power meter disk **18** according to equation 2. The values for these parameters are given in elements a and b above. In this particular example, the display unit **14** can synchronize the displayed cycle count with the cycle count that is transmitted by the detection unit **12**. The display unit **14** can then use the cycle count and the latest revolution time to predict future cycle counts until the next transmission is received. If on the next transmission, the display unit **14** has "over-predicted" and is displaying a higher consumption rate than the real corresponding cycle count, then one option is to not update the display unit **14** until the real energy consumption value "catches-up" to the predicted value. This is to prevent the display unit **14** from showing a lower consumption value after it had previously displayed a higher consumption value. If however the power meter disk **18** speeds up, then on the next data transmission, the display unit **14** will display a sudden "jump" in energy consumption.

[0043] The compression unit **48** receives the generated information and compresses this information to provide the information signal **36** which is then transmitted by the transmitter **28**. The compression reduces the length of the generated information. As a result, the transmitter **28** does not expend as much energy in transmitting the information signal **36**. This is beneficial since wireless communication can be a key cause of energy dissipation. However, there must be an acceptable balance between a reduction in the amount of data that is transmitted for reducing energy consumption and an acceptable level of information loss that is introduced by compression.

[0044] Alternatively, the compression unit **48** can be used to compress the raw data in the consumption detection signal **32** or a series of values for

the prediction model parameters that have been calculated over a given time period. This is beneficial in the case where data transmissions from the detection unit **12** to the display unit **14** are not that frequent. This situation can arise when a consumer does not want real-time feedback but wants to review the energy consumption once a day or possibly once a week. In this case, the information provides resolution between successive data transmissions; i.e. the consumer can get an idea of the average energy consumption between successive data transmissions, however, by transmitting more information, the consumer can get an idea of what happened in energy consumption between the two transmission times and may see transient increases or decreases in energy consumption of the structure.

[0045] The compression unit **48** uses a compression method that is easy to compute using a standard low powered microcontroller. Any compression method that exceeds the memory capacity of the memory unit **50**, the time between scheduled updates to the display unit **14**, or the power to transmit the data is not effective. It should also be noted that if too much data is compressed and the message sent containing the information is lost or corrupted then there is no way to recover the data without resending the data. However, limitations of the memory unit **50** may prevent the resending of data. Further, the estimation of the power consumption due to the compression method is based on the number of bits needed to represent the compressed time series. The fewer the number of bits needed to represent the compressed time series, the less power required to transmit the same amount of information.

[0046] Several compression methods can be used to compress a time series such as, but not limited to, Wavelets, Fourier Transforms, Piecewise Linear Approximations and polynomials. In addition, once a compression method is selected, an acceptable compression error ϵ_{comp} is preferably specified. The compression error ϵ_{comp} represents the amount of information that can be reasonably lost due to compression. This allows the algorithm to compress the data such that when it is uncompressed the values are within

ϵ_{comp} of the original data values. Once set, the prediction error ϵ_{comp} may be dynamically changed. However, it is preferable that the dynamic value of the prediction error never exceed the originally set ϵ_{comp} because this value specifies the maximum allowable error. In general, the greater the ϵ_{comp} the higher the compression rate that can be achieved and thus a greater reduction in power consumption.

[0047] In this case, the data to be compressed is power consumption data which is a time series $\mathbf{x}[\mathbf{n}]$ that has a plurality of data elements in which the index n is a time index and the values associated with a time index is the current demand. if the data series is graphed, the area under is the graph is the power consumption. The demand can be calculated by multiplying the kWh factor of the power meter unit **16** with the constant 3600 and dividing by the latest revolution time of the power meter disk **18** that is associated with the current time index. The success of a compression technique depends on the presence of an underlying deterministic process in the time series $\mathbf{x}[\mathbf{n}]$. An example of a compression algorithm is the following. The compression error ϵ_{comp} defines a maximum error in the compression algorithm. The algorithm begins with taking the first two raw data points without compression. These two data points are successive absolute cycle counts and the times at which they occur. From this a revolution time can be calculated (alternatively the kinematic equation can be used for the revolution time) and the demand is calculated as explained above. The demand and the time index is added to the compressed data series. The next demand point is repeatedly calculated and only added to the compressed data series if the absolute value of the magnitude of the demand point minus the magnitude of the previous demand point in the compressed data series is larger than the prediction error ϵ_{comp} . If the absolute value of the difference is larger than the magnitude of the demand point and the corresponding time index is added to the compressed data series. This procedure continues until there are no more data points to compress. It should be understood that rather than save the demand value, the corresponding revolution time can be saved instead since these values

are related to one another by a factor. In another alternative, the absolute cycle count at the time index may also be saved in the compressed data series. Also, rather than saving the value of the demand or revolution time, the delta (i.e. difference between the current demand or revolution time and the previous value) can be saved. The compression ratio (CR) that can be achieved is represented by equation 3:

$$CR = \frac{K(b_s + b_{tp})}{nb_s} \quad (3)$$

where K is the compressed sequence length; b_s is the size of the sample in terms of bits; b_{tp} is the size of the time index in terms of bits and n is the number of samples in the original time series prior to compression which represents the number of times that the rate of rotation of the power meter disk **18** is checked. The memory unit **50** is memory that is associated with the processing unit **12**. The memory unit **50** is preferably an EEPROM. However, depending on the implementation of the processing unit **24**, the memory unit **50** may be RAM or another suitable memory device that has low power consumption. The memory unit **50** is used to save important parameters that are needed for the operation of the detection unit **12** and that can not be lost should power to the detection unit **12** be removed. For instance, the memory unit **50** can save instructional code that the control unit **42** uses to control the operation of the detection unit **12**. The memory unit **50** is also preferably used to save the absolute cycle count.

[0048] The tracking unit **44**, prediction unit **46** and compression unit **48** operate independently of each other. Accordingly, alternate embodiments of the detection unit **12** can incorporate one or more of these units and it is not necessary that the detection unit **12** contain each of these units. However, the greatest amount of reduction in energy consumption for the detection unit **12** is achieved when the detection unit **12** contains all of these units. However, if both compression and prediction are used, if the compression error ϵ_{comp} is equal to the prediction error ϵ_{pred} , then there is no benefit to compression because the values of the prediction model parameters will be updated often

enough to allow the display unit **14** to construct the same representation of the data that compression would have constructed. It is therefore necessary to set the prediction error ϵ_{pred} higher than the compression error ϵ_{comp} . Effectively, this means that data for a certain amount of time (T_c) is compressed and that the data is transmitted every (T_p) seconds due to the amount of prediction error that is tolerated and that T_p is greater than T_c (i.e. having a larger prediction error allows one to use the same values for the prediction model parameters for a longer period of time, since over time the prediction error will accumulate).

[0049] The display unit **14** comprises a receiver **52**, a display processing unit **54**, a real-time clock **56**, a receiver memory unit **58**, a display **60**, an interface unit **62**, a buzzer unit **64** and an appliance control unit **68**. Some of these elements may be optional such as the buzzer unit **64**, the appliance control unit **68** and the real-time clock **56** if another means can be obtained to provide time. The display unit **14** may be plugged into a wall receptacle to receive power from the mains supply or the display unit **14** may have an internal power source such as a battery (not shown) that is connected in known manner.

[0050] The receiver **52** receives the transmission signal **38**, performs the necessary demodulation and pre-processing, as is commonly known to those skilled in the art, and generates a received signal **66** that is similar to the information signal **36**. Data will typically be sent in data packets in the transmission signal **38**. During the generation of the received signal **66**, the receiver **52** checks the device address data in the received data packets to ensure that the transmission signal **38** was received from the appropriate transmitter **28** and not from a transmitter of a different power meter reader system. If the receiver **52** determines that the transmission signal **38** was provided by the transmitter **28** of a different power meter reader system, then the receiver **52** will discard the received data packets. The receiver **52** also checks the CRC data in the data packets of the transmission signal **38** to make sure that data integrity is maintained during transmission. If a

discrepancy is found in the CRC data, there is an error in the data packets of the transmission signal **38** and the receiver **52** discards these data packets. Further, continuously "listening" for the transmission signal **38** is power consuming. Accordingly, the transmitter **28** and the receiver **50** preferably employ unidirectional communication from the transmitter **28** to the receiver **52**.

[0051] The receiver **52** provides the received signal **66** to the display processing unit **54** for further processing. The display processing unit **54** extracts the time for the last revolution of the disk and the cycle count, and uses the same prediction model that was used by the prediction unit **46** (if prediction is employed) to display the instantaneous demand in Wh or kWh or \$/hr (rather than dollars another appropriate form of currency can be used depending on the country in which the power meter reader system is being used). The display processing unit **54** also uses this information to display a disk on the display **60** that spins at the same rate as the power meter disk **18**. The display processing unit **54** also extracts the power source voltage status information and the temperature reading to display this information on the display **60**. If the power source voltage is low, then the display processing unit **54** will display a battery low symbol on the display **60**.

[0052] The display processing unit **54** uses the prediction model parameters to predict the amount of energy consumption that occurs until the next data transmission from the detection unit **12**. In one example, the detection unit **12** sends over the absolute cycle count (which is never reset in the detection unit **12**) and the last revolution time. The receiver uses these two values to predict the occurrence of successive revolutions of the power meter disk **18**.

[0053] The display processing unit **54** can also allow the consumer to predict energy consumption for a specified time into the future, and also has the ability to store a history of energy consumption in the memory unit **56**. Accordingly, the display processing unit **54** employs prediction on a longer time scale to allow the consumer to predict energy consumption for the next

billing cycle (i.e. 30 days) for example (a similar prediction model can be used as those previously described except with a longer time period). The long term prediction (i.e. long-range bill prediction) can use linear regression based on the energy consumption in the last several days (i.e. the energy consumption is saved daily by the display unit **14**) to predict the amount of the future energy bill.

[0054] The display processing unit **54** can also use the revolution count information to display the amount of greenhouse gas that the structure, which consumes the power, is responsible for emitting. This calculation is based on the region in which the structure is located since it is based on carbon-dioxide emission rates which are specific for a particular region or utility company. In particular, the display processing unit **54** can show the amount of carbon-dioxide that has been emitted in terms of tones, pounds or kilograms. Alternatively, the display processing unit **54** can display environmental credits/token/units that have been accumulated, used or that are remaining. These tokens may be distributed by the government or an environmental agency. The display processing unit **54** may also display a warning signal to notify the user of excess consumption; this may include but is not limited to a graphic on the display **60** such as a smoke stack, a sad face and/or a beep provided by the buzzer unit **64**. The carbon-dioxide emission rates based on the province, state and/or country in which the power meter reader system **10** is used can be pre-programmed into the display processing unit **54**. The consumer can then simply select their location on the display unit **14**.

[0055] The real-time clock **56** is used to maintain time in the display unit **14**. The time is received by the display processing unit **54** for computing the current time and displayed on the display **60**. The time is also used by the display processing unit **54** in conjunction with Time of Use Energy Rates. For instance, depending on the particular utility company, the consumer may be charged different rates for energy consumption depending on the time of day when the energy is consumed. This is done to reduce energy consumption at peak times. For example, between 5 PM and 8 PM. a utility company may

charge 10 cents/kWh rather than 6 cents/kWh so that the consumer reduces energy consumption between 5 and 8 PM.

[0056] The memory unit **58** can be any suitable memory device such as an EEPROM. The memory unit **58** is used to store critical information so that the display unit **14** can be powered down and powered back up without losing important information. Examples of critical information include different rates for energy consumption based on location, the cumulative energy consumed, the number of days to use for long-range bill prediction, etc.

[0057] The display unit **60** can be any suitable display device such as an LCD. The display unit **60** is used to display time and date information, power consumption in dollar amounts (or other currency), or other consumption units such as kWh, carbon-dioxide emission levels, and a disk that spins at the same rate as the power meter disk **18** as well as other information. The display unit **60** is described further below in an exemplary embodiment.

[0058] The interface unit **62** can be a keypad or similar device which allows the user to enter information into the display unit **14** or to choose between various modes of operation. The buzzer unit **64** provides an audible sound to provide various information to the consumer. For instance, the buzzer unit **64** may sound an alarm when the voltage level of the power source **30** of the detection unit **12** is running low. The buzzer unit **64** can also provide a sound to verify that the consumer has depressed a key on the interface unit **62**. Any suitable buzzer can be used.

[0059] The appliance control unit **68** can be used in conjunction with the information that is provided by the detection unit **12** to direct the operation of appliances within the structure for which energy consumption is being monitored. The appliance control unit **68** is connected to the structure's powerline to send appliance control signals to the appliances via a powerline communications device. Any suitable powerline communications device can be used such as the X10™ or CEBUS™ powerline devices. The appliances have a corresponding receiver module with a unique address. Accordingly,

the appliance control unit **68** can send specific control instructions to a particular appliance. These control instructions can direct the appliance to turn on, turn off, to increase an operational setting or decrease an operational setting. For example, the appliance can be an air conditioner and a control instruction may be to decrease the amount of cold air provided by the air conditioner.

[0060] In use, the appliance control unit **68** receives at least one of temperature information, energy consumption information and time information from the display processing unit **54** and uses this information to control an appliance. For instance, based on temperature information, and depending on the season and the particular temperature, the appliance control unit **68** can instruct a heating or cooling appliance to increase or decrease its operational setting. Alternatively, based on energy consumption, the appliance control unit **68** may instruct several appliances to turn off to conserve energy if the current level of energy consumption is too high. In another alternative, based on the time of day, the appliance control unit **68** can instruct one or more appliances to turn off. For instance, some utilities charge a higher rate during peak periods to encourage consumers to consume less energy. During these times periods, the appliance control unit **68** can instruct some of the more power hungry appliances to turn off. Of course, these instructions are within reason; i.e. it is not reasonable to turn off a fridge since the contents within the fridge may spoil. Rather than having the appliances turn off, the appliance control unit **68** can alter the operation level of the appliances.

[0061] Referring now to Figure 2, shown therein is a block diagram of another exemplary embodiment of a power meter reader system **10'** with an alternative display unit **14'**. In this case, the display unit **14'** includes a communication unit **70** for communicating with a computing device such as a PC **72**. The communication unit **70** can be an RS232 data interface, a USB port or any other suitable communication device. The PC **72** can be connected to the display unit **14'** and runs a utility software program **74** to

interact with the receiver 52. The software on the PC 72 can be used to upload the history of energy consumption from the display unit 14' so that the consumer can make graphs, etc. to determine when the most energy is being consumed. It should be understood by those skilled in the art that another appropriate computing device can be used rather than a PC.

[0062] The consumer can also use the PC 72 to connect with a website provided by a utility web server 76 over the internet 78. The consumer may browse the web site to view utility rates, view consumption patterns and get energy saving hints and green house gas information. The utility web server 76 would obtain this information from an associated utility database 80. The consumer can also download carbon-dioxide information from the website and provide this information to the utility software program 74 which then passes this information to the display unit 14'.

[0063] Referring now to Figure 3a, shown therein is an exemplary embodiment of a sensor unit 100 that can be used with both of the power meter reader systems 10 and 10'. The sensor unit 100 comprises an emitter 102, a first detector 104 and a second detector 106. In this embodiment, two detectors are used to make the sensor unit 100 more robust to false detections as well as ambient light. Furthermore, in this embodiment, the sensor unit 100 receives a polling signal 108 from the control unit 42 as well as the enable control signal 40. The sensor unit 100 also provides first and second detection signals 110 and 112 that are combined to form the consumption detection signal 32. In terms of physical layout, the emitter 102 is located between the first detector 104 and the second detector 106 (this is illustrated in Figures 3b-3f and discussed in more detail below).

[0064] The enable control signal 40 is combined with the VCC power supply signal in a logical AND operation by the AND gate 114. Accordingly, when the enable control signal 40 is high, the VCC power supply signal is provided to the remainder of the circuitry of the sensor unit 100 thereby enabling the sensor unit 100. Otherwise, the sensor unit 100 is in sleep mode with no power consumption. Alternatively, rather than having the AND gate

114, other suitable devices may be used such as a CMOS transistor or a more complex transmission gate. It should be understood that capacitors to ground can be connected in parallel with **VCC** to remove noise.

[0065] In an alternative, the AND gate **114** can be replaced by a transmission gate; i.e. a CMOS transistor for example, can be used. Alternatively, the **VCC** power supply signal can be provided by a pin on a microcontroller if a microcontroller is used to implement the control unit **42** and a sufficient amount of current can be provided by the pin.

[0066] In this exemplary embodiment, the emitter **102** comprises a light emitting diode (LED) **D1** connected in series with a resistor **R1** and a transistor **Q1**. The resistor **R1** is connected to the output of the AND gates **114** and to a first node of the LED **D1**. The other node of the LED **D1** is connected to the collector of the transistor **Q1** and the emitter of the transistor **Q1** is connected to ground. The base of the transistor **Q1** is connected to a first node of a resistor **R2**. The other node of the resistor **R2** is connected to the polling signal **108**. In use, when the sensor unit **100** is enabled and the polling signal **108** is pulsed high, the transistor **Q1** is turned on and conducts current which allows the LED **D1** to emit light. The LED **D1** is selected such that it emits infrared light. The LED **D1** may emit modulated IR light at a frequency of 38 kHz for example although other modulation frequencies may be used such as 2 kHz for example. The detection signals **110** and **112** are then filtered by a bandpass filter that has a passband that matches the modulation frequency used to emit the IR light. The bandpass filtering can be done in hardware (not shown) or via software by a unit within the processing unit **24**.

[0067] The first detector **104** and the second detector **106** are preferably implemented to have the same structure so that the first and second detection signals **110** and **112** are similar to one another. Accordingly, only the first detector **104** will be described. The first detector **104** comprises a photodiode **D3** connected in series with a resistor **R6**. A first node of the photodiode **D3** is connected to the output of the AND gate **114** and a second

node of the photodiode **D3** is connected to the resistor **R6**. The other node of the resistor is connected to ground. The series combination of the photodiode **D3** and the resistor **R6** is connected in parallel with a series combination of a resistor **R4** and a transistor **Q3**. A first node of the resistor **R4** is connected to the output of the AND gate **114** and a second node of the resistor **R3** is connected to the collector of the transistor **Q3**. The base of the transistor **Q3** is connected to the second node of the photodiode **D3**. The emitter of the transistor **Q3** is connected to ground.

[0068] In use, when the sensor unit **100** is enabled and the polling signal **108** is pulsed high, the LED **D1** emits IR light that is reflected by the shiny surface of the power meter disk **18**. In this case, the black mark **20** has not come into the vicinity of the LED **D1** or the photodiode **D3**. Accordingly, the photodiode **D3** is conducting, the transistor **Q3** is turned on and current flows through resistor **R4**. Accordingly, there is a voltage drop across the resistor **R4** and the voltage at the emitter of the transistor **Q3** is relatively constant and has a low magnitude with respect to the power supply voltage **VCC**. However, when the LED **D1** shines IR light on the black mark **20**, not as much energy is reflected by the power meter disk **18**. Consequently, the photodiode **D3** turns off, no current flows through the resistor **R6** and the transistor **Q3** turns off. Accordingly, only a small amount of current flows through the resistor **R4** and a high voltage with respect to the power supply voltage **VCC** is seen at the emitter of the transistor **Q3** and hence in the first detection signal **110**.

[0069] Referring now to Figures 3b-3f, shown therein is an illustration of the operation of the sensor unit **100**. The LED **D1** and the photodiodes **D2** and **D3** are oriented with the photodiodes **D2** and **D3** on either side of the LED **D1**. These elements are spaced according to the angular extent of the black mark **20** which is typically 5 degrees or so. In one exemplary embodiment, these elements are separated by approximately 3 or 4 mm. This spacing is also chosen to ensure that reflections from small black specks on the power meter disk **18** will not trigger both photodiodes. In addition, these elements have a

plastic shield between them so that light from the LED **D1** does not go directly to either photodiode **D2** or **D3**. Further, the voltage from each photodiode **D2** and **D3** can be subtracted from one another to cancel out any common mode voltage caused by IR going directly to the photodiodes.

[0070] Figure 3b includes a series of panels that depict the different cases for the location of the black mark **20** on the power meter disk **18** with respect to the location of the emitter **102** and the first and second detectors **104** and **106**. These five cases are represented by a state machine with five corresponding states. The state machine is implemented in the control unit **42**. Figure 3b shows the case where the black mark **20** has yet to reach the emitter **102** and the first and second detectors **104** and **106**. In this case, the output of the first and second detectors is a low logic level (i.e. 0). Figure 3c shows the case where the black mark **20** is close to the emitter **102** and the first detector **104** but not the second detector **106**. Consequently, the output of the first detector **104** is a high logic level (i.e. 1) and the output of the second detector **106** is a low logic level. Figure 3d shows the case where the black mark **20** is close to the emitter **102** and the first and second detectors **104** and **106**. In this case, the outputs of the first detector **104** and the second detector **106** are both a high logic level. Figure 3e shows the case where the black mark **20** is close to the emitter **102** and the second detector **106** but not the first detector **104**. In this case, the output of the first detector **104** is a low logic level and the output of the second detector **106** is a high logic level. Figure 3f shows the last case in which the black mark **20** is far from the emitter **102** and the first and second detectors **104** and **106**. In this case, the outputs of the first and second detectors **104** and **106** are both low logic levels. Accordingly, based on the outputs of the first and second detectors **104** and **106**, the passage of the black mark **20** can be detected. In particular, the consumption detection signal **32** can be based on the logical AND of the first and second detection signals **110** and **112**.

[0071] The use of two detectors allows for more robust operation of the sensor unit **100** and less false detections. For instance, there may be spurious

detections by either the first detector **104** or the second detector **106** which may be due to dirt on the power meter disk **18** and the like. However, it is very unlikely that both detectors **104** and **106** will give a spurious detection at the same time. Furthermore, it is very unlikely that noise will trigger a detection if one requires that all five states happen sequentially before making a detection of the passage of the black mark **20** by the sensor unit **100**.

[0072] In an alternative, the five states can be reduced to three states by subtracting the first and second detection signals **110** and **112** from one another and noting the change in sign in the subtraction signal. For instance, the subtraction result for each of the five states, beginning with the first state and moving sequentially to the last state and subtracting the second detection signal **112** from the first detection signal **110**, is 0, 1, 0, -1 and 0. Accordingly, the transition from 1 to 0 to -1 signifies the passage of the black mark **20** past the sensor unit **100** and makes it very unlikely that glitches or noise will result in a false detection.

[0073] Referring now to Figure 4, shown therein is an example of a general transmission data structure **120** that may be used for transmitting data in either of the power meter reader systems **10** and **10'**. This transmission protocol can be useful when the display unit is configured to interact with more than one detection unit (i.e. monitor the energy consumption of more than one structure) wherein each detection unit can operate in a different manner. In addition, other transmission data structures may be used that only have a portion of the fields contained in the transmission data structure **120**. All efforts have been made to reduce the complexity and overhead of the transmission data structure **120** to reduce energy consumption in the detection unit **12**. The transmission data structure **120** will not be effective if the overhead to transmit the data is greater than the data itself. The numerals 7 through 0 at the top of Figure 4 signify the number of bits that are used to make up a particular piece of information in the transmission data structure **120**.

[0074] The transmission data structure **120** comprises a battery level field **122**, a battery voltage field **124**, a listen policy field **126**, a listen period field **128**, an E_compression field **130**, an E_prediction field **132**, a history length **134**, a first history length field **136**, a second history length field **138**, a compressed history data field **140**, a first current value field **142**, a second current value field **144**, a prediction model field **146**, a first model parameters field **148** and a second model parameters field **150**. The battery level field **122** is sent for all transmissions made to the display unit **14**. The battery level can be used to warn the end user of the display unit **14** that the detection unit **12** is getting low on power. Although some batteries have a sharp voltage drop curve as battery power dissipates, most batteries will give fair warning that they are getting low on power. The battery level field **122** is composed of 5 bits allowing for 32 distinctive levels of the battery voltage based on a linear scale.

[0075] The battery voltage field **124** shows an initial battery voltage for the power source **30**. The initial battery voltage can be represented by eight values (i.e. 3 bits provide 000 sequentially through to 111). As an example, the following voltage levels can be represented: 1.2V, 1.5V, 2V, 2.4V, 3V, 3.6V, 4V and 6V. The initial battery voltage may also be coded in the display processing unit **54** since it is quite likely that the size of the battery used with the detection unit **12** is known a priori. However, there may be several different styles of detection units **12** that can use different size batteries.

[0076] The listen policy field **126** indicates to the display unit **14** when to listen for messages from the detection unit **12**. In an unpredictable scheme where transmission occurs whenever the prediction error value ϵ_{pred} is violated, the policy for the display unit **14** will most likely be set to always listen for transmissions. However, the detection unit **14** could set a short transmission window and only be able to broadcast during this time window (as set in the policy). In this case, the detection unit **12** has the option of whether to send data, set a new listening policy or do nothing at all during each window. However, if the detection unit **12** detects a violation of the

compression error ϵ_{comp} too often and is running out of memory to store the data or the prediction error ϵ_{pred} is violated, the detection unit **12** has to wait for the next transmission window to send data. In the worst case this could result in erroneous data predicted by the display unit **14** and/or a loss of data by the detection unit **12**. The detection unit **12** must also be careful not to set too long of a transmission period as memory overflow may occur in the detection unit **12** and data will be lost. The display unit **14** could use the policy to identify potential interference between multiple detection units **12** (i.e. two or more detection units that want to broadcast at exactly the same time). It would then be up to the display unit **14** to take the appropriate action to resolve the conflict. Although in a unidirectional communication situation it may be difficult to resolve the conflict without human intervention (in this case, the consumer would shut down the detection unit **12** and the display unit **14** to reset these units). As shown in Table 1, the policy could be to broadcast every n Minutes, n Hours or n Days, where n is defined by the listen period field **128**. If the listen policy field **126** is set to a time period of *Minutes*, *Hours* or *Days* then the 6 bits in the listen period field **128** allow for a listening period between 1 and 64 of the specified time period (i.e. 1 to 64 minutes, 1 to 64 hours or 1 to 64 days).

Table 1. Values for the Listen Policy Field

| Code | Policy |
|------|---------|
| 00 | Always |
| 01 | Minutes |
| 10 | Hours |
| 11 | Days |

[0077] The $E_{\text{compression}}$ field **130** specifies the amount of compression error ϵ_{comp} between true sensor readings and the compressed values in the data that is transmitted. This value can range from 0 in the lossless case to up to 255 for a very lossy compression scheme. The value in the $E_{\text{compression}}$ field **130** can be dynamically decided upon by the compression unit **48** during compression.

[0078] The E_prediction field **132** specifies the amount of prediction error $\varepsilon_{\text{pred}}$ between the predicted values, due to the prediction model, and the actual values before updated values for the model parameters are transmitted by the detection unit **12** to the display unit **14**. This value can range from 0, which is the case where any violation of the prediction will result in a transmission, up to 255. The value in the E-prediction field **132** can be dynamically updated by the prediction unit **46**. For example, if the power source **30** is running very low, then this value may be increased so that fewer transmissions are made by the detection unit **12**. However, it is important that the display unit **14** is aware of any possible error in the predicted values of energy consumption so that the consumer can be properly notified via a graphical output on the display **60**.

[0079] The first and second history length fields **134** and **136** represent the length of data in the compressed history data field **148**. The first and second history length fields **134** and **136** are specified by 12 bits in total to represent data lengths from 0 to 4096 data points. The minimum length 0 is specified when there is no data that is transmitted.

[0080] The compression type field **138** consists of 4 bits and specifies the type of compression used for the data in the compressed history data field **140**. For example, if the first bit in the compression type field **138** is a 1, the delta of the predicted series and the compressed series is compressed. Alternatively, if the first bit of the compression type field **138** is a 0, then the raw sensor values are compressed. For different segments of a time series, different compression schemes may work better. Accordingly, the compression unit **48** can pick the best compression algorithm for a given portion of data and represent the particular compression algorithm in the compression type field **138**. However, memory limitations in the detection unit **12** may not allow large blocks to have variable compression schemes. The various compression schemes that can be used are represented in table 2 (currently two entries are reserved for using other different types of compression). The entry NONE indicates that no compression is used.

Table 2: Types of data compression

| Code | Compression |
|------|-------------|
| 0000 | NONE |
| 0001 | PMC-Raw |
| 0010 | Reserved |
| 0011 | PMC-Delta |
| 0100 | Reserved |

[0081] The compressed history data field **140** is the compressed data that is collected by the detection unit **12**. The length of the data in the compressed history data field **100** is specified in the history length fields **134** and **136** (to a max of 8192 bytes) and the type of compression used is specified in the compression type field **138**. As mentioned previously, the data in the compressed history data field may be a series of values for the prediction model parameters or may be the actual raw data. This is useful in situations where the system **10** or **10'** is configured for long times in between data transmissions. For example, this may be once per day and the consumer does not want real-time updated data but the consumer does want to see what happened with power consumption at various times during the day.

[0082] The current value fields **142** and **144** represent the latest absolute non-compressed current reading from the detection unit **12**. This value represents the cycle count up to (i.e. absolute cycle count) the latest detected revolution of the power meter disk **18** prior to the current data transmission. If a time index is necessary, then the time index should be added to the data in the compressed history field **140**.

Table 3. Meanings for values in the Current Value Fields

| Code | Meaning |
|-----------------|----------------|
| 0x0000...0xFFFE | Sensor Reading |
| 0xFFFF | No value |

[0083] The prediction model field **146** indicates the type of prediction model used by the display unit **14** to predict the values between transmissions

from the detection unit **12**. Exemplary representations in the prediction model field **146** are shown in Table 4. The entry NONE indicates that no prediction is used.

Table 4. Meanings for values in the Prediction Model Field

| Code | Prediction |
|------|------------|
| 0000 | NONE |
| 0001 | Last |
| 0010 | Linear |
| 0011 | Reserved |

[0084] The model parameters field **148** provides the values for the prediction model parameters that were generated by the prediction unit **46** according to the chosen prediction model. However, if the prediction model field **148** specified that the prediction model is NONE, then all but the first four bits of this message will be encoded.

[0085] The transmission data structure **120** shown in Figure 4 gives no indication of the error-correcting code (ECC) that is to be used during data transmission. A strong ECC will have to be used in the case of unidirectional communication if the detection unit **12** does not resend its information. Otherwise the data sent by the detection unit **12** may not be recoverable. Some examples of ECC include convolutional encoding and checking such as VITERBI algorithms. The ECC works with an error detection code. In one instance, CRC data can be added to the data transmitted and then used at the receiver to provide error checking on the transmitted data. First the ECC is used to fix potential errors but if there are more errors than can be corrected the CRC is a fail safe mechanism to throw out the message.

[0086] Referring now to Figure 5, shown therein is a front view of an embodiment of the display unit **160** that can be used with either of the power meter reader systems **10** and **10'**. The display unit **160** includes a display **162**, a keypad **164**, a communication port **166** and a power connection port **168**. The display **162** includes a number of display fields: a quantity display field

170, a unit display field **172**, a power meter disk display field **174**, a date display field **176**, a time display field **178** and a low battery indicator field **180**. The quantity display field **170** displays a numerical quantity such as the quantity of power consumption or the temperature. The quantity display field **170** can display a \$ symbol when displaying power consumption in a dollar amount. The quantity display field **170** may also display icons that indicate whether the quantity being displayed is for current energy consumption, total energy consumption or future predicted energy consumption. The unit display field **172** displays an appropriate unit for the quantity being displayed in the quantity display field **170**. The unit display field **172** can display the following units: °C, °F, lbs CO₂, kWh, etc. The power meter display field **174** displays a digital representation of the power meter disk **18** including the black mark **20**. The digital representation of the power meter disk **18** rotates at the same speed that the actual power meter disk **18** rotates. This field can also provide a relative indication of the amount of energy consumption, such as a big dollar sign or a little dollar sign, to signify whether there is currently a large or small amount of energy that is being consumed. The date display field **176** displays the current date and the time display field **178** displays the current time. The low battery indicator field **180** can provide a display of a battery that is almost empty to indicate that the detection unit **12** is running out of power.

[0087] The keypad **164** includes an up-scroll key **182**, a down-scroll key **184** and a select key **186**. The up-scroll and down-scroll keys **182** and **184** allow the user to scroll through different options such as scrolling through the type of numerical data that is to be displayed on the display **162**, or scrolling through the different locations so that the consumer may select the location in which the power meter reader system is being used, etc. The select key **184** is used to select one of the options.

[0088] The communication port **166** is used to connect the display unit **160** to a computer or another suitable computing device, as described in the description of the power meter reader system **10'**. The power connection port

168 is used to connect the display unit **160** to a power source. Most likely, an adaptor may be used to connect the display unit **160** to an electrical outlet.

[0089] Referring now to Figures 6a, and 6b, shown therein are views of an exemplary physical embodiment of a detection unit **200** of the power meter reader system attached to a power meter **202**. The power meter **202** is a conventional meter with a durable outer casing **204**, a cover **206**, a power meter disk **208** and a plurality of dials **210**. The cover **206** is made of glass or plastic, has circular sidewalls with a flat front face and is transparent to allow an individual to read the dials **210** which indicate power consumption. The power meter disk **208** is usually made from aluminum or another suitable metal, and is flat with a black mark at a predetermined location along its outer edge. The power meter disk **208** rotates about a vertical axis at a rate that is dependent upon the current drawn by the structure which is being monitored by the power meter **202**; the more current that is used, the faster the power meter disk **208** rotates. The power meter **202** is sealed to provide protection from the elements and to prevent tampering with the power meter disk **208** and the dials **210**. The power meter **202** is of conventional construction the inner workings are known by those skilled in the art. It should be noted that power meter **202** is shown for exemplary purposes and that the display unit **200** can be mounted to other different power meter designs.

[0090] The detection unit **200** has been specially designed to fit and work with different shapes and sizes of power meters. The detection unit **200** has also been specially designed so that it does not block the power meter disk **208**, the dials **210** or the serial number when it is attached to the power meter **202** so that a person from the utility company can read the power meter **202** if needed. The detection unit **200** includes a main body **212**, an extension member **214** and an attachment means **216** for attaching the detection unit **200** to the power meter **202**. The main body **212** houses most of the electronics of the detection unit **200**.

[0091] The extension member **214** houses the sensor unit **22** in a head region **218**. The extension member **214** also includes a longitudinal extension

means **220** and a pivot means **222** for positioning the sensor unit **22** over the power meter disk **208**. In this embodiment, the longitudinal extension means **220** comprises a slot **220a** and a fastener **220b** (in this case a screw for example, although other suitable fasteners may be used). The extension member **214** is extended over the face of the power meter **200**, via the longitudinal extension means **220**, until the head region **218** of the power meter **200** is directly over an appropriate region of the power meter disk **208**. In particular, the head region **218** is preferably located so that the sensor unit **22** lies directly over the center of the power meter disk **208** because this is the location at which the black mark on the power meter disk **208** comes closest to the front face of the power meter **202**. Accordingly, this is the point at which the SNR of reflected signals will be highest for the sensor unit **22**. The fastener **220b** is then placed through the slot **220a** to engage a borehole **220c** (see Figure 6c) in the main body **212** to maintain the extension member **214** with a certain amount of extension and at a certain angle with respect to the main body **212**. In this embodiment, the fastener **220b** and the borehole **220c** also provide the pivot means **222**. The extension member **214** can be placed at an angle other than 90 degrees (as is currently depicted in Figures 6a and 6b) with respect to the main body **212**. It should be understood by those skilled in the art that other implementations are possible for the longitudinal extension means **220** and the pivot means **222**. For instance, the extension member **214** can include a telescopic section for implementing the longitudinal extension means **220**.

[0092] The attachment means **216** is used to attach the detection unit **200** to the power meter **202**. In this embodiment, the attachment means **216** includes a hose clamp **224** that slidably, releasably engages a loop member **226** on the main body **212** and extends around the perimeter of the power meter **202** to secure the detection unit **200** to the power meter **202**. The hose clamp **224** is preferably made from a durable material that is either flexible (or thin enough to be flexible) such as steel. The hose clamp **224** has a series of serrations so that the clamping portion (not shown) can attach at a number of positions to accommodate power meters **202** with a variety of different

diameters. However, in general, any appropriate clamping means can be used for the attachment means such as clamps that include a lever, a latch (such as an over-center latch), or a ratchet means for providing a tight fit for the attachment means.

[0093] Referring now to Figure 6c, shown therein is an exploded isometric view of the main body **212** and the extension member **214** of the detection unit **200** of Figure 6a. The main body **212** includes a first piece **212a** and a second piece **212b** which are molded to provide a friction fit with one another. The head region **218** includes a first piece **218a** and a second piece **218b** that are also molded to provide a friction fit with one another.

[0094] It should be understood by those skilled in the art that while the power meter unit **16** described herein is as an electromechanical meter, the power meter reader system of the invention may also work with a digital power meter unit. Digital power meter units provide an output that emulates the rotation of the power meter disk. The output is usually on an LED screen and could be a mark that rotates, or flashes or travels horizontally at the same rate as the black mark on the power meter disk **18** would rotate. In each of these cases, the sensor unit **22** of the invention can be used to sense the movement of the mark. Accordingly, in general, the power meter reader of the invention, and more particularly the sensor unit **22**, monitors a cyclical property of an indication on a power meter reader that has a varying period that indicates power consumption. The cyclical property could be the rotation of the black mark on the power meter disk, the flashing of a mark on an LED screen, the rotation of a mark on an LED screen or any other repetitive movement of the mark on the LED screen. In these cases, the sensor unit **22** still operates in a sleep mode when before and after the mark indicates the completion of one cycle that is similar to one cycle or rotation of the power meter disk **18**.

[0095] In addition, in another alternative, the digital power meter may emit infrared energy that indicates the power consumption of the structure. In this case, infrared energy is not emitted by the sensor unit **22**. Rather, the

receiver of the sensor unit **22** operates as previously described, i.e. using sleep mode and tracking to reduce power consumption, while detecting rotations of the simulated power meter disk. The remainder of the power meter system works as previously described. Further, the transmission protocol that is used to reduce power consumption does not depend on whether the power meter unit is electromechanical or digital.

[0096] The elements of the power meter reader system **10** shown in Figures 1, and 2 may be implemented by any means known in the art although the use of dedicated hardware such as a controller with associated memory may be preferable. Furthermore, certain components of the motion compensation unit **10** may be implemented by the same structure. For instance, the tracking unit **44**, the prediction unit **46** and the compression unit **48** may be implemented by the same hardware structure. Furthermore, some of the components can be implemented in software as is known to those skilled art which may be written in C, C⁺⁺, or any other suitable programming language embodied in a computer readable medium on a computing platform having an operating system and the associated hardware and software. The computer program may comprise computer instructions that are adapted to perform the functionality of some of the components of the processing unit for example. The computer programs may comprise modules or classes, as is known in object oriented programming, that are implemented and structured according to the structure shown in Figures 1 and 2; separate software modules may be designed for the components. Alternatively, the functionality of these components may be combined into a smaller number of software modules where appropriate.

[0097] It should be understood that various modifications can be made to the embodiments described and illustrated herein, without departing from the invention, the scope of which is defined in the appended claims. For instance, the display unit need not be installed in the structure that is consuming power since there are some applications in which one display unit can be linked to several detection units so that power consumption of several

structures can be monitored from a central location. In this case, the display unit needs to be augmented to recognize the identity of several detection units and keep separate records for each detection unit.